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	7th year programme. **Formulae given in frames may be quoted without proof in answers to Baccalaureate questions. Candidates for the Baccalaureate may be required to derive other formulae. Timings are suggested, not obligatory.**	
Section F. Field Physics. **F 1. Energy in the inverse square field.**	To separate two bodies of masses m_1 and m_2 from separation r_a to separation r_b requires an amount of work given by $W = Gm_1m_2(1/r_a - 1/r_b)$.	Gravitational potential may be introduced.
F1.1 The gravitational field.	Revision of work from year 6, sections M2.4, M2.5, M4.3. Conventionally **gravitational potential energy** is taken as zero at infinite separation. This implies that gravitational potential energies are negative, since the gravitational force is attractive. **Gravitational Potential Energy** $E_p = -Gm_1m_2/r$ *in a radial gravitational field* The **escape velocity** for a body at radius r from a planet of mass M (for example) is consequently given by $v_{escape} = [2GM/r]^{1/2}$ The mechanics of circular movement imply that the kinetic energy of an orbiting body is $E_k = Gm_1m_2/2r$, implying a total energy for a satellite of $-Gm_1m_2/2r$.	Calculations of the mass of the sun and of planets; orbital speed. The journey to the moon.
F1.2 The electric field.	By exact analogy, the total energy of a light charged particle in circular orbit around a stationary massive charged particle follows. **Electrical Potential Energy** $E_p = -Q_1Q_2/4\pi\varepsilon_0 r$ *in a radial electric field*	

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F1.3 The electron volt.	For small particles, of atomic or subatomic dimensions, it is convenient (especially if they are charged) to measure their energy in a smaller unit than joules. The energy of a particle whose charge is equal to that of the electron, which has been accelerated from rest by a p.d. of 1v, is defined as **1 electron volt** (1eV). **Electron Volt** Unit: eV Definition: *the energy equivalent to that of an electron accelerated from rest by a p.d. of 1V.*	
F 2. Energy in the uniform field.		
F2.1 The uniform gravitational field.	Revision of basic work from years 4 and 5, and from 6th year, M3.1.	
F2.2 The uniform electric field.	Revision of work from year 6, F1.1 – F.1.3.	
F2.3 The magnetic field.	Since the force on a moving charged particle in a magnetic field is perpendicular to its velocity vector, there is no work done and hence no modification of the particle's kinetic energy.	
F3. Movement of a particle in a field.		
F3.1 Uniform gravitational fields.	Revision of work from year 6, M1.4	
F3.2 Uniform electric fields.	As in the uniform gravitational field, the general movement of a charged particle in a uniform electric field is parabolic.	
F3.3 Uniform magnetic fields.	The equations governing the movement of a charged particle in a magnetic field imply that the general movement is helical; the helix degenerates to a circle if the velocity and intensity vectors are perpendicular and to a straight line if they are parallel. The radius of the circular movement is given by $r = mv/Bq$. [Note: *Here as elsewhere a rigorous vector treatment is unnecessary, but pupils should be able to use a practical rule to deduce the sense of the force*].	Analogies with free fall and with ballistic problems. The linear accelerator.

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F3.4 Applications. ***Time: 32 periods (F)***	A magnetic field may be used to distinguish particles according to their masses, as in the mass spectrometer. Electric fields can be used to speed particles up, as in the electron gun. Electric or magnetic fields can be used to deflect them as in the oscilloscope or the television tube. Electric and magnetic fields in combination can be used to select particles by velocity or to accelerate them, as in a cyclotron. Other simple uses of fields in parallel and perpendicular combination are not excluded.	Other accelerators, e.g. the synchrotron. The electron microscope, magnetic lenses, Millikan.
Section W. Waves. **W1. Basics.** **W1.1 Definitions. Sinusoidal waves.**	A system of oscillators, arranged so that the energy from one may be communicated by some mechanism to its neighbours, can give rise to the propagation of a **progressive wave.** Thus energy is transported without the bulk movement of any mass. Waves may be **transverse** or **longitudinal** in nature, according to whether the disturbance is respectively perpendicular or parallel to the direction of energy travel. If the disturbance y of a given oscillator is given by $y = A \sin \omega t$ (see year 6), then it is termed a **harmonic** or sinusoidal oscillator, and ωt is known as its **phase angle**. The disturbance of a neighbouring oscillator will be identical in amplitude, assuming no energy loss, but different in phase angle. Its disturbance will therefore be $y' = A \sin(\omega t - \Delta\phi)$, where $\Delta\phi$ is the difference of phase angle between them. The phase angle changes linearly with displacement in the direction of movement of the wave, for a given value of time. [**Note**: *the term "Phase" does not have the same implications in all languages. In the European Schools it is appropriate, to avoid possible contradictions and problems of translation, to refer to the* ***phase angle*** *at a point rather than the phase at a point, for example.*]	Demonstrations with coupled pendula etc.
W1.2 Equation of a progressive wave.	In a progressive wave, the phase angle of a given oscillator will change by 2π in time $2\pi/\omega$. This is the **period T** of the wave. the phase angle of an oscillator is modified by 2π for two oscillators separated by distance λ. This is the **wavelength**. for two oscillators separated in distance by Δx and in time by Δt, the difference in phase angle is $\Delta\phi = 2\pi\Delta t/T - 2\pi\Delta x/\lambda$ The equation of a progressive wave is $y = A \sin(2\pi t/T - 2\pi x/\lambda)$ A wave may thus be defined as **doubly periodic** (in space and in time).	

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	The speed of propagation of a wave is $\Delta x/\Delta t = \lambda/T = f\lambda$, and expresses the speed of movement of a wavecrest (or other point of given phase angle).	
W1.3 Huyghens' principle.	A progressive wave may be considered to propagate by the generation of secondary wavelets along its wavefront.	
W1.4 Examples.	**General note:** *The concept of a wave allows apparently very dissimilar phenomena to be described by very similar wave models. This aspect should be emphasized in this section, by underlining the similarity of the behaviour (for example) of sound and radio, rather than their contrasts.*	
	Sound or Acoustic waves may be propagated in solids, liquids and gases. In air, the speed of propagation is about 340 ms^{-1} at room temperature, but is temperature dependent. Sound waves are longitudinal in gases. Transverse waves may be propagated on wires with a velocity dependent on tension and linear density.	**Velocity of waves on a wire:** $c^2 = F/\mu$ where $\mu = m/l$ (the linear density of the wire)
W2. Behaviour. **W2.1 General**	Electromagnetic waves have a very large range of frequencies and can be used to carry information (radio), to see by (light), and for medical purposes (x-rays) according to the frequency used. They are transverse, may travel through a vacuum, and do so independently of their frequency with a velocity c which is one of the fundamental constants of physics. It is not necessary to examine in depth why they are called electromagnetic and how they are propagated, at this level.	**Velocity of sound waves:** $c \propto \sqrt{T}$ where T is the absolute temperature.
	Refraction, reflection, diffraction, interference and the **Doppler effect** may be observed in all waves.	
W2.2 Refraction.	A train of waves which change their propagation velocity, usually because of some modification of the medium in which they travel, will also modify their wavelength in proportion (but not their frequency). At oblique incidence this leads to a change in direction. If the angles with the normal to the interface between the media are α and β, and the velocities are c_1 and c_2 in the two media respectively, then $\sin\alpha/\sin\beta = c_1/c_2$.	The phenomena should be demonstrated with as diverse a range of waves as possible (light, sound, ripple tank, microwaves, ultrasound....)

Refractive Index of a medium

Symbol: n

Definition: $n = c/c'$ where

c = wave speed in a vacuum

c' = wave speed in the medium

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W2.3 Reflection.	A train of waves **reflect** from a surface with an "equal angles" law. If the surface from which the reflection takes place is of a medium in which the wave's velocity would be lessened, the reflection is accompanied by a **phase angle change** of π.	
W2.4 Diffraction.	A plane wave passing through an aperture will "spread out" to an extent which depends on the wavelength and on the aperture size. This effect is significant in proportion to λ/d, where d is the width of the aperture. Similar behaviour occurs when a wave encounters an obstacle.	
W2.5 Interference. **2.5.1 Basics.**	Two waves which coincide at a point in space and time will give a resultant disturbance which is the sum of the individual disturbances. This is the **principle of superposition.** If this results in an increase in amplitude (reinforcement) there is **constructive interference.** If the amplitude is reduced, there is **destructive interference.** For superposition of identical waves, the resultant wave will have an amplitude between zero and double that of the two interfering waves. If the sources of the two waves are situated at points A and B, and are in phase, then at any point P, interference is constructive if the **path difference** is a whole number of wavelengths, and destructive if it is an odd number of half wavelengths.	Beats
2.5.2 Coherence.	Stable interference behaviour will be observable only between two waves which have a constant phase relationship to one another. Such waves are said to be **coherent**. Sources of such waves are **coherent sources.**	
	Path difference. Symbol: δ Unit: m Definition: $\delta = \lvert PA - PB \rvert$ at a point P where A and B are the positions of two coherent sources.	
2.5.3 Stationary waves.	These result from the interference of identical waves travelling in opposite directions. **Nodes** and **Antinodes** result at points of destructive and constructive interference, which are at fixed positions in space. The waves must be from coherent sources; but they may in general be of any frequency. Points at which interference is destructive (called **displacement nodes**) are separated by half a wavelength, and between each pair of nodes there is a **displacement antinode** at which interference is constructive.	

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	[**Note:** *in French the term "stationary wave" seems only to be used for waves which exist on a bounded medium, when one wave is produced by reflection of another, see below. Care must be taken to avoid problems of translation when preparing Baccalaureate questions.*]	
2.5.4 Bounded media; fundamentals and overtones.	A most important case of stationary waves arises when the medium in which the waves propagate is **bounded**. The only strong stationary waves which can exist are those which match the physical conditions forced at the boundary. Only certain well defined values of frequency can be supported by the system with any significant amplitude. The lowest frequency possible is known as the **fundamental**; the other frequencies are known as **overtones**, and their frequencies are simply related to the fundamental. In the formulae which follow, n denotes the overtone number, and λ_0 the wavelength of the fundamental. [**Note:** *the use of the terms "overtone" and "harmonic" and their equivalents varies between languages. Great care must therefore be exercised in the setting and translation of Baccalaureate questions if ambiguity and contradiction are to be avoided. The term "First Harmonic" does not, for example, have the same meaning in French as it does in English.*] On a string or in an open pipe; $\lambda_n = \lambda_0/(n+1) = 2l/(n+1)$ (both ends displacement nodes or both antinodes) In a pipe closed at one end; $\lambda_n = \lambda_0/(2n+1) = 4l/(2n+1)$ (one end a displacement node, one an antinode)	Resonance tube experiments; Melde, Kundt.... Organ pipes, and other wind and string instruments.
2.5.5 Double source interference.	If two coherent sources of waves which are in phase are situated at points A and B which are a distance d apart, a stationary wave will exist along AB (see above); but elsewhere (for points which are not on AB) a system of strong progressive waves may be observed which is symmetrical about the mediator of AB. For observers at a large distance from AB compared to its length d, the path difference δ at an angle x from the mediator of AB will be $\delta = d \sin x$. Thus waves of high amplitude arrive because of constructive interference at points where $\sin \theta_k = k\lambda/d$. (k is known as the **order** of the maximum). Waves of low amplitude arrive because of destructive interference at points where $\sin \theta = (2k-1)\lambda/2d$	The single slit diffraction pattern, and its modulation of the double slit pattern, may be treated if the level of the group permits.

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	If in addition to the above condition, the angle θ is small, and if D is the distance of the observer from AB, then $\sin\theta_k \approx \theta_k \approx \tan\theta_k = x_k/D = k.\lambda/d$ for a maximum of intensity, where x_k is the distance of the k^{th} maximum from the symmetry axis, whence it follows that the maxima of intensity are equally spaced with separation $D\lambda/d$.	Refractometers, the Michelson Interferometer, Lloyd, Fresnel..
2.5.6 The diffraction grating.	The **diffraction grating** allows maxima of higher intensity to be observed at the same angles and positions, and also narrows the maxima making them easier to locate. A detailed explanation of these differences from the double slit case is not required.	
W2.6 The Doppler Effect. ***Time: 34 periods (W)***	When a source of waves S, of frequency f_0, and an observer O are in relative motion parallel to OS, the observed frequency f' of the waves will be given by $f' = c'/\lambda'$, where c' and λ' are the observed velocity and wavelength of the wave. The observed frequency is therefore affected if the source and the observer are approaching or receding from one another. **Observed frequency change – source and observer approaching one another .** $\Delta f/f \approx v/c$ *(for v<<c)* *where v is the speed of approach, c is the wave speed in the medium (if any).*	A capable group might treat the “moving source” and “moving observer” cases for sound.
Section D. The dual character of matter and radiation. **D.1 General.**	It is usual to consider electrons and other particles as behaving like small objects having mass, and radiation such as light as wave motions, for reasons justified by their behaviour studied above. However, in the case of certain aspects of their behaviour a reversal of these models is required.	
D.2 Corpuscular behaviour of light. **D2.1 The photoelectric effect.**	Electrons are emitted from an illuminated pure metal surface in a manner which cannot be satisfactorily explained by considering light as a wave. There is no emission at all for light which is below what the wave theory would call a certain frequency, known as the **threshold frequency**. Above this frequency, electrons are emitted immediately, with a maximum kinetic energy which varies linearly with the “frequency” of the light, and an abundance dependent upon its intensity. The value of this threshold frequency varies with the nature of the metal concerned.	Discharge of the electroscope on exposure to radiation.

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	This behaviour is perfectly accounted for, quantitatively and qualitatively, by assuming light to be propagated by **corpuscles or photons** whose energy varies directly with classical frequency. A given metal has a threshold of energy below which no emission of electrons takes place. This quantity is the **work function** of the metal.	
D2.2 Measurement of Planck's constant.	Abundance and maximum ke of emitted electrons may be measured using a photocell with suitable power supplies and measuring instruments. Pupils should be familiar with this experiment, and with its use to measure Planck's constant. $hf = W_0 + KE = W_0 + \frac{1}{2} mv^2 = W_0 + eV_{stop}$, and $W_0 = hf_0$.	
D2.3 Momentum of light.	A beam of light (or a stream of photons) may be shown to possess **momentum** which increases with decreasing wavelength. **Work Function** Symbol: W_0 Unit: joule J Definition: *The minimum energy to extract an electron from a given metal's surface.* **Photon energy** $E = h.f$ *where h is Planck's constant.* **Photon momentum** $p = h/\lambda$	Light sail, solar wind, Crooke's radiometer. The Compton Effect.
D.3 Wave behaviour of particles		
D3.1 Diffraction of particles.	Beams of particles with small mass display wave-like behaviour, and are able to diffract and interfere like beams of light.	
D3.2 De Broglie waves.	The behaviour of such particles may be quantitatively described if they are taken to have a **De Broglie wavelength** inversely proportional to the momentum, which corresponds with the expression for photon momentum above.	

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	De Broglie wavelength $\lambda = h/mv = h/p$	
D3.3 Applications. ***Time: 14 periods (D)***	The very small wavelengths of electrons make them useful for microscopy, because they are less affected by diffraction than light. Normal diffraction gratings are not fine enough to be useful, but a crystal lattice will cause analogous interference effects. For electron beams reflected from crystal surfaces, successive layers of molecules give rise to multiple reflected beams which can interfere in the usual way. Thus maxima of intensity are observed when $\sin \phi_n = n \lambda/2d$, where d is the lattice spacing.	
Section A. Atomic physics. **A.1 Generalities. The nuclear atom.**	The experiments of Rutherford suggested that atoms have a very small, massive, positively charged core which is known as the nucleus, accompanied by electrons.	
A.2 Series.	Atoms which are excited by electrical bombardment, as in a discharge tube, can emit light. Various frequencies are present, arranged in a number of different series. These photons get their energy from energy loss due to modifications in the configuration of the electrons. The fact that the frequencies are always the same and are sharply defined implies that only specific energies are possible.	Experiments with discharge tubes.
A.3 Eigenvalues for the Hydrogen atom. ***Time: 14 periods (A)***	The requirement that an orbiting electron's wave must be in phase with itself at all points in the orbit to enable constructive interference to take place implies that an electron can only orbit at radii where $n\lambda = nh/mv = 2\pi r$. Historically this is called the Bohr condition.	Discussion of the idea of a model; all models have inadequacies.
	Along with the classical mechanics of electron orbit (section F.1) this allows calculation of the total energy of the hydrogen atom as $E_n = - me^4/8\varepsilon_0^2h^2n^2$ and the frequencies of the emitted photons are $f_n = me^4/8\varepsilon_0^2h^3[1/n^2 - 1/m^2]$ where m and n have integral values. This accords with observation; different values of n give the different series.	The Franck-Hertz experiment suggests electronic energy levels exist in Mercury atoms. Fast groups might look at laser action.
	The lines of the **Balmer series** (given by n = 2) lie in the visible part of the spectrum. The energy to cause **ionization** is $E = me^4/8\varepsilon_0^2h^2$	

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Section N. Nuclear Physics.		
N.1. Elementary particles.	Revision of work from 4th year, section N.	
N1.1 Descriptions.	The nucleus is formed of the nucleons (proton and the neutron). Pupils should know the basic facts about masses, charges and composition of the nucleons, the electron (β- particle) and the α - particle.	
N1.2 Units.	The atomic mass unit is the “u”; the masses of the neutron and of the proton are approximately 1u. **The unit of atomic mass** Symbol: ***u*** Definition: ***1u = 1/12 mass of a Carbon-12 atom.***	
N1.3 The nucleus.	Nuclei are made from a number of **protons** (Z) and a number of **neutrons** (N). The total mass of the nucleus in u is approximately $A = N+Z$	
N1.4 Notation.	A nuclide with N neutrons and Z protons is represented by $^{A}_{Z}X$. The number of electrons for a neutral atom is equal to the atomic number Z, which therefore controls the chemical identity of the atom. Variations are possible in the number of neutrons; this gives different **isotopes** of the same element. [**Note:** *national textbooks seem to disagree about whether the symbol used above properly denotes an atom or a nucleus; furthermore the terms “nuclide”, and “isotope” are frequently used loosely in textbooks. It is therefore important in the writing of Baccalaureate questions that the context or the text of the question makes clear what is intended when this notation or terminology is used, in cases where the difference is important.*]	
N.2 Nuclear reactions		
N2.1 Stable and unstable nuclei.	Some isotopes are stable, but many more disintegrate spontaneously. These are known as **radioisotopes**, and are said to be **radioactive**. When they break up, the great majority emit α- or β- particles.	The cloud chamber; photographic emulsions; the Geiger-Muller tube.
N2.2 γ –rays.	Like the atom, it is possible for a nucleus itself to exist in an excited energy state, and to lose energy of excitation spontaneously. This energy may be emitted as a high frequency photon, or γ- ray.	

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N2.3 Mass-energy equivalence.	The theory of relativity allowed the old conservation laws of mass and energy to be assimilated to one principle, by describing the equivalence of these two quantities. Thus the total of mass/energy in a system is a conserved quantity. **Mass-energy** An amount m of mass is equivalent to an amount E of energy, where $E = mc^2$.	
N2.4 Mass defect and binding energy.	The mass of a nucleus at rest is found to be less than that of the sum of its parts at rest. The amount by which the mass is reduced is the **mass defect** – Δm. Mass/energy is thus released on assembling a nucleus; expressed as energy, this quantity is also known as the **binding energy**, and it must be restored in order to dismantle the nucleus. **Binding energy** $\mathbf{E} = -\Delta mc^2$	
N2.5 Binding energy per nucleon.	If the mass defect is divided by the number of nucleons in the nucleus, the binding energy gives an idea of how difficult it is to remove one nucleon, and thus of the **stability** of the nucleus.	
N2.6 Artificial radioactivity.	Light elements may be made heavier by artificial means, notably by neutron bombardment and absorption. Sometimes this process can cause the stability of a nucleus to be destroyed.	
N2.7 Fission and fusion.	Two nuclei can join together to form one heavier nucleus; this is known as fusion. A heavy nucleus can also split into two parts; this is fission. The binding energy per nucleon, as a function of atomic mass, is of such a form that light elements release energy on fusion and heavy ones on fission. In particular, fission can provoke chain reactions (e.g. in Uranium-235 and Plutonium). Charge (atomic number) and mass number are conserved in these and other nuclear reactions.	Stars.

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N2.8 Application of conservation laws.	Pupils should be able to apply the law of conservation of linear momentum to problems involving nuclear interactions and reactions (see 6th year programmes, **M3.2**) as well as the law of conservation of mass/energy.	
N2.9 Reactors.	No deep understanding of the technology of nuclear reactors is required, but candidates should know the function of **moderators, fuel elements and control rod**s.	
N.3 Radioactive decay. **N3.1 Definitions.**	The number of decays per second observed in a sample of a radioisotope is defined as the **activity** of the sample, and is found to be proportional to the number of nuclei present. The constant of proportionality is known as the **decay constant**; this may be interpreted as the probability of one atom of the isotope decaying in unit time. **Activity** Symbol: A Unit: becquerel Bq Definition: The number of decays or events per second Relation: $A = -dN/dt$ **Decay constant** Symbol: λ Unit: s^{-1} Definition: $\lambda = A/N = -(dN/dt)/N$	Decay of Thorium. Units of dose (Gray, Sievert) may be introduced to an able group, as may historic and other units (Curie, rem, rad).
N3.2 Exponential decay; Half-life.	The equations above imply an exponential relation between the number of atoms, mass and activity of a radioisotope and time. $N = N_0e^{-\lambda t}$ $m = m_0e^{-\lambda t}$ $A = A_0e^{-\lambda t}$. As a consequence the time taken for a given fraction of the radioisotope to decay is characteristic of the isotope. The time for half to decay is known as the **half-life** and is given by $T_{½} = \ln 2/\lambda$.	
N3.3 Radioactive series. ***Time: 14 periods (N)***	The radioactive series associated with an element terminates with a stable isotope.	